arXiv:1005.4526v1 [hep-ph] 25 May 2010

Collective flow in (anti)proton-proton collision at Tevatron and LHC

Tanguy Pierog(1), S. Porteboeuf(2), Iu. Karpenko(3,4), K. Werner(4)
(1) *Karlsruhe Institut of Technology, Institut für Kernphysik, Postfach 3640, 76021 Karlsruhe Germany*
(2) *LLR, Ecole Polytechnique, Palaiseau, France*
(3) *Bogolyubov Institute for Theoretical Physics, Kiev 143, 03680, Ukraine*
(4) *SUBATECH, University of Nantes – IN2P3/CNRS– EMN, Nantes, France*

Collective flow as a consequence of hydrodynamical evolution in heavy ion collisions is intensively studied by theorists and experimentalists to understand the behavior of hot quark matter. Due to their large mass, heavy ions suffer collective effects even at low (SPS) or intermediate energies (RHIC). In case of light systems such as (anti)proton-proton interactions, collective effects was not expected. Within a global model such as EPOS, where light and heavy systems are treated using the same physics, it appears that Tevatron data are better described if a flow is introduced. Then the extrapolation to LHC can easily be done and we can compare to first data from ATLAS experiment.

1 Introduction

There seems to be little doubt that heavy ion collisions at RHIC energies produce matter which expands as an almost ideal fluid[1,2]. This observation is mainly based on the studies of azimuthal anisotropies, which can be explained on the basis of ideal hydrodynamics[3]. A big success of this approach was the correct description of the so-called mass splitting, which refers to quite different transverse momentum dependencies of the asymmetries for the different hadrons, depending on their masses.

As it was pointing out already in 2007 in [4], a model which describe properly these effects for heavy ion interactions will predict the same mechanism already for (anti)proton-proton interactions when the “centrality” is large enough (high multiplicity in the central region). And it can be compared to Tevatron data[5] where such effects are clearly visible in the dependence of the average transverse momentum with central multiplicity (including mass splitting) as shown fig. 1.

After a short introduction on the EPOS model section 2, we will compare its results to the latest ATLAS data at 900 GeV and show section 3 that the same effect is already visible event at this relatively “low” energy. In the section 4, we will present how a correct calculation of collective effects can be done in the framework of the EPOS model.

2 EPOS Model

One may consider the simple parton model to be the basis of high energy hadron-hadron interaction models, which can be seen as an exchange of a “parton ladder” between the two hadrons.

In additions to the parton ladder, hadronized using strings (flux-tube), there is another source of particle production: the two off-shell remnants.

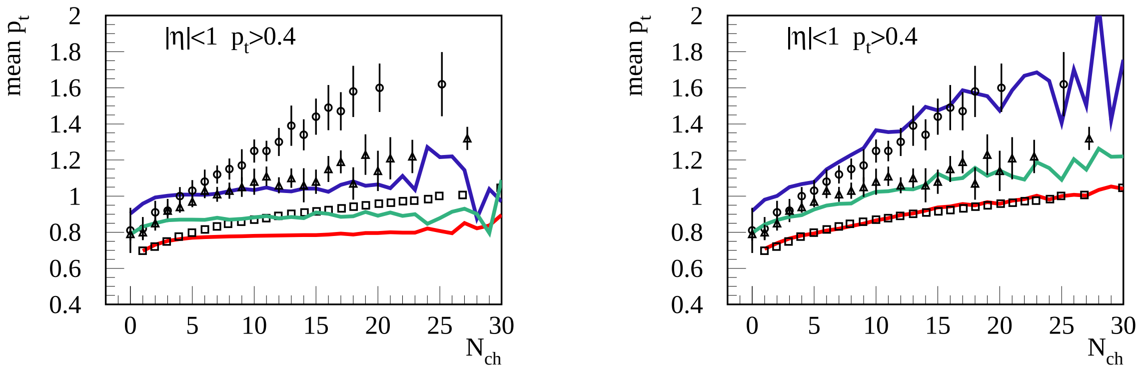

Figure 1: Average transverse momentum $\langle p_t \rangle$ as a function of central multiplicity of charged particles for different particle types (from top to bottom : lambdas, kaons short and charged particles). Points are data from CDF experiment [5]. Line are simulations with EPOS without hydro (left hand-side) and with hydro (right hand-side).

EPOS [6] is a consistent quantum mechanical multiple scattering approach based on partons and strings, where cross sections and the particle production are calculated consistently, taking into account energy conservation in both cases. Nuclear effects related to Cronin transverse momentum broadening, parton saturation, and screening have been introduced into EPOS. Furthermore, high density effects leading to collective behavior in heavy ion collisions are also taken into account. In next section preliminary results are shown using an effective treatment using a parameterized flow (not using LHC data). The full hydrodynamic treatment described in section 4 applied to (anti)proton-proton will be shown in a paper in preparation.

3 Comparison to LHC data

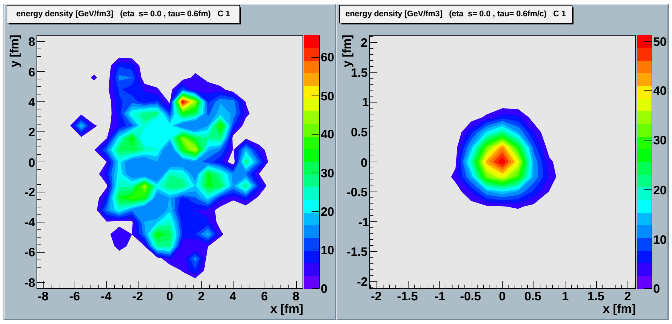

Figure 2: Energy density in central Au-Au (L) and pp (R) scattering at 200 GeV resp. 7T́eV.

Let us consider the energy density at an early time in a Au-Au scattering at RHIC, as obtained from an EPOS simulation [6]. In the left hand-side of fig. 2, we plot the energy density at the space-time rapidity $\eta_s = 0$, as a function of the transverse coordinates x and y . We observe a very bumpy structure concerning the $x - y-$dependence. There are in particular peaks in the $x - y-$plane which are sub-flux-tubes which exhibit a long range structure in the longitudinal variable η_s.

In fig. 2 , we clearly identify several sub-flux-tubes, with a typical width of the order of a fermi. This is exactly the width we obtain if we compute the initial energy density in proton scattering at the LHC (fig. 2 right hand-side). This means, if a hydrodynamic treatment is justified for Au-Au collisions at RHIC, it is equally justified for pp scattering at the LHC, provided the energy densities are high enough. This latter condition can easily be satisfied, since in proton-proton scattering on has the possibility to trigger on high multiplicity events, with ten or twenty times the multiplicity compared to an average event.

If collective effects are possible in light system, how can it be observed ? Besides correlations between particles, one of the striking consequence of a collective hadronization is the creation of a radial velocity. In case of heavy ion collisions, the asymmetry created by the impact parameter allows the measurement of the v_2 parameter of the flow to quantify this effect. In case of anti(proton)-proton scattering, it is experimentally difficult to define a "collision plane" and actually it was never done or even foreseen to measure v_2 in that case. But the radial flow increase the transverse momentum of the particles, so that this effect should change the mean transverse momentum $\langle p_t \rangle$. A measure of the energy density is given by the multiplicity of charged particles N_{ch} event-by-event. As a consequence the variation of the $\langle p_t \rangle$ as a function of N_{ch} has to be sensitive to the collective effects in a very light system.

The effect shown in fig. 1 for Tevatron at 1.8 TeV is actually confirmed at 900 GeV by the ATLAS experiment [8]. In fig. 3 we can see the difference between simulation with (full line) or without (dashed line) hydrodynamic evolution of the high density region. This effect has only little influence on the total multiplicity has shown in fig. 4.

4 Hydrodynamics in EPOS

In future version of EPOS, we are going to employ a new tool for treating the hydrodynamic evolution, based on the following features (see [7] for details and tests with AuAu data):

- initial conditions obtained from a flux tube approach (EPOS), compatible with the string model used since many years for elementary collisions (electron-positron, proton proton), and the color glass condensate picture;
- consideration of the possibility to have a (moderate) initial collective transverse flow;
- event-by-event procedure, taking into the account the highly irregular space structure of single events, being experimentally visible via so-called ridge structures in two-particle correlations;
- core-corona separation, considering the fact that only a part of the matter thermalizes;
- use of an efficient code for solving the hydrodynamic equations in 3+1 dimensions, including the conservation of baryon number, strangeness, and electric charge;
- employment of a realistic equation-of-state, compatible with lattice gauge results – with a cross-over transition from the hadronic to the plasma phase;
- use of a complete hadron resonance table, making our calculations compatible with the results from statistical models;
- hadronic cascade procedure after hadronization from the thermal system at an early stage.

5 Summary

EPOS is an interaction model constructed on a solid theoretical basis. It has been tested very carefully against all existing hadronic data. Designed to be compared to heavy ion collisions, the collective effects are being implemented in a very sophisticated way. Based on a realistic event-by-event energy density with large fluctuations, a 3D hydrodynamical calculation is performed

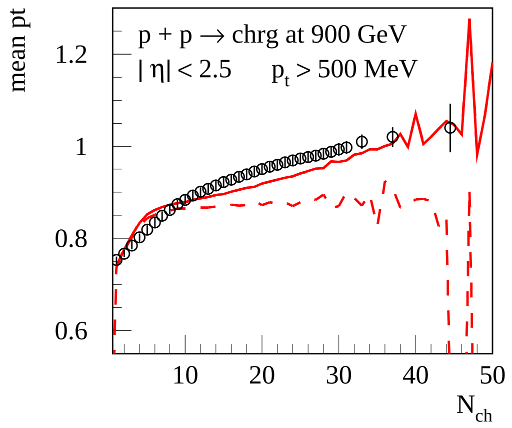

Figure 3: $\langle p_t \rangle$ as a function of multiplicity of charged particles for proton-proton collisions at 900 GeV. ATLAS data points[8] are compared to EPOS simulations with (full line) or without (dashed line) hydro evolution.

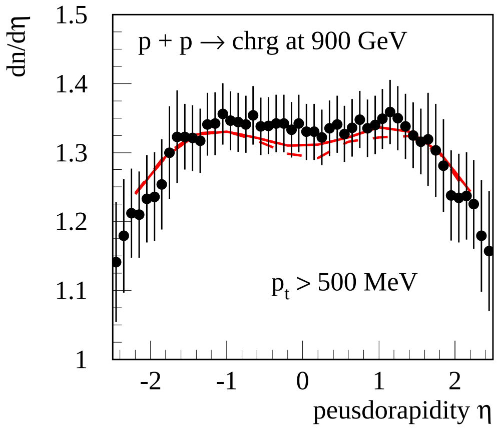

Figure 4: Pseudorapidity distribution of charged particles with $p_t > 500$ MeV for proton-proton collisions at 900 GeV. ATLAS data points[8] are compared to EPOS simulations with (full line) or without (dashed line) hydro evolution.

until chemical freeze-out followed by a hadron cascade until thermal freeze-out. Applying the same scheme for (anti)proton-proton scattering at high energy, the most inelastic collisions will actually satisfy the conditions to create a small thermalized system which will hadronized statistically and with a non-negligible radial velocity. We showed that this effect is visible in the dependence of the $\langle p_t \rangle$ with the particle multiplicity of each event at Tevatron or LHC energies, especially if we look at the dependence with the mass of the particles. Further detailed measurements at LHC (correlations) will allow us to actually test the space-time evolution of the energy density of hadronic interactions.

Acknowledgments

This research has been carried out within the scope of the ERG (GDRE) “Heavy ions at ultra-relativistic energies”, a European Research Group comprising IN2P3/CNRS, Ecole des Mines de Nantes, Université de Nantes, Warsaw University of Technology, JINR Dubna, ITEP Moscow, and Bogolyubov Institute for Theoretical Physics NAS of Ukraine. Iu. K. acknowledges partial support by the MESU of Ukraine, and Fundamental Research State Fund of Ukraine, agreement No F33/461-2009. Iu.K. and K.W. acknowledge partial support by the Ukrainian-French grant “DNIPRO”, an agreement with MESU of Ukraine No M/4-2009. T.P. and K.W. acknowledge partial support by a PICS (CNRS) with KIT (Karlsruhe).

References

1. STAR Collaboration, J. Adams, *et al*, *Nucl. Phys.* A **757**, 102 (2005)
2. PHOBOS Collaboration, B.B. Back *et al.*, *Nucl. Phys.* A **757**, 28-101 (2005)
3. Quark-Gluon Plasma 3, eds. R. C. Hwa and X. N. Wang (World Scientific, Singapore, 2004)
4. N. Armesto *et al.*, *J. Phys.* G **35**, 054001 (2008).
5. CDF Collaboration, D. E. Acosta *et al.*, *Phys. Rev.* D **72**, 052001 (2005).
6. K. Werner *et al.*, *Phys. Rev.* C **74**, 044902 (2006).
7. K. Werner *et al.*,arXiv:1004.0805, submitted to *Phys. Rev.* **C**.
8. ATLAS Collaboration, G. Aad *et al.*, *Phys. Lett.* B **688**, 21 (2010).